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Revisiting Ryugu's pre-/post-mission thermal observations: emissivity determination

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Thermalphysical models are widely used to interpret thermal measurements of near-Earth and main-belt asteroids (e.g., Delbo et al. 2015), and in some cases also for icy trans-Neptunian objects (e.g., Müller et al. 2020). The derived radiometric sizes, albedos and thermal properties are reliable when good-quality spin-shape solutions are available and when multi wavelength thermal measurements are available for different phase angles. However, these techniques are not well tested for cases where the majority of the thermal measurements were taken in the short-wavelength regime below the thermal emission peak, e.g., from warm Spitzer-IRAC, WISE-W1/W2 bands, or groundbased observations up to the M-band around 5 μm.

Müller et al. (2017) analysed a collection of pre-mission thermal measurements of 162173 Ryugu, the Hayabusa-2 target asteroid. The data set was dominated by short-wavelength Spitzer-IRAC data at 3.55 and 4.49 μm, complemented by a Spitzer-IRS spectrum and a few individual data points at longer wavelenghts. The best-fit radiometric size (850-880 m), albedo (0.044-0.050) and thermal inertia (150-300 $Jm^{-2}s^{-0.5}K^{-1}$) agree very well with in-situ properties (896 m, 0.045, 300 ± 100 $Jm^{-2}s^{-0.5}K^{-1}$; Watanabe et al. 2019; Okada et al. 2020). However, the radiometric solution from 2017 pointed towards a smooth surface. A very low roughness in the TPM setup was required to explain the short- and long-wavelength data simultaneously. This is in strong contrast to the results derived from the Hayabusa-2! Close-proximity measurements of Ryugu obtained by the visual and infrared instruments of Hayabusa-2 revealed a surface roughness rms of $47^\circ \pm 5^\circ$ (Shimaki et al. 2020), a high value when compared to lunar surface with a rms of surface slopes of 32° (Rozitis et al. 2011; Bandfield et al. 2015). So, what went wrong in the 2017 pre-mission TPM study?

We repeated the analysis of the pre-mission IR measurements of Ryugu but now using the in-situ size, shape, spin (Watanabe et al. 2019) and surface roughness properties ($47^\circ \pm 5^\circ$; Shimaki et al. (2020)). In a first step, we used a standard constant spectral emissivity of 0.9. This default $\varepsilon=0.90$ assumption leads to a best-fit thermal inertia above 1000 $Jm^{-2}s^{-0.5}K^{-1}$ in the radiometric χ^2 minimalisation technique (e.g., Alí-Lagoa et al. 2020). In a second approach, we applied a spectral emissivity derived from high-accuracy disk-integrated measurements of the Moon (Müller et al. 2021). The lunar emissivity curve has a minimum value of about 0.7 around 4.5 μm and steeply increasing towards the Christiansen feature in the 7.5-9 µm regime. As a result, we found a very consistent TPM solution for Ryugu for thermal inertias between 150 and 400 Jm^{-2}s$^{-0.5}$K^{-1}, very close to the published values of about 300 Jm^{-2}s$^{-0.5}$K^{-1} (Okada et al. 2020) and 225 ± 45 Jm^{-2}s$^{-0.5}$K^{-1} (Shimaki et al. 2020). This example illustrates the importance of realistic spectral emissivity in the context of radiometric studies for short-wavelenghs (<<10 µm) thermal observations.

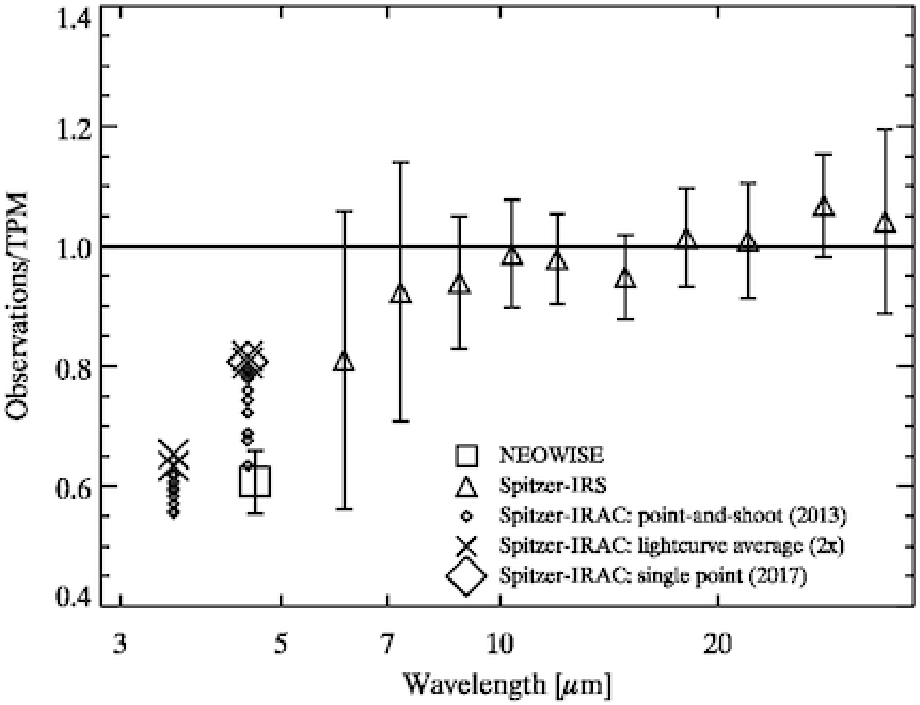

Figure 1: *Multiple thermal-IR observations of Ryugu, divided by the corresponding TPM predictions with the assumption of a constant emissivity of ε=0.9. Model predictions are based on spin, shape, size, albedo, thermal inertia, and surface roughness properties derived from Hayabusa-2 in-situ measurements. The Spitzer-IRS (Campins et al. 2009) and the Spitzer-IRAC point-and-shoot and two IRAC lightcurve measurements from 2013 were already discussed in Müller et al. (2017). The IRAC single point from 2017 (J. Hora, M. Mommert, priv. comm.), as well as the NEOWISE data point (J. Masiero, priv. comm.), are not published yet. The thermal data below 5 µm show very clear indications for a low-emissivity Ryugu surface. Note that the reflected light contribution at the shortest wavelength at 3.55 µm was well below 5% in all cases.*

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